Anaerobic Digestion and Fermentation Technology: Feasibility Study

# Anaerobic Digestion

*Process Description*

Anaerobic digestion is the conversion of organic matter into methane in the absence of oxygen. The main products of this process are Biogas (approx. 60:40 methane to carbon dioxide), and a Digestate- a liquid/solid residue that the water will be obtained from.

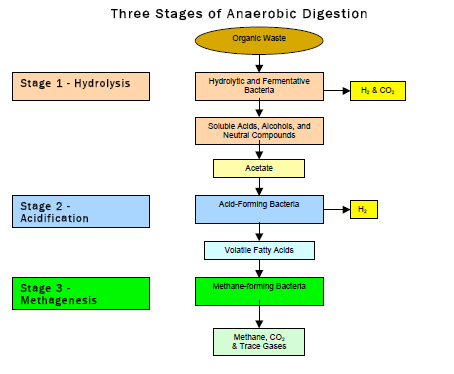
The digestion takes place over three stages which can be viewed in the Figure 1 below.  
  


Figure 1: Stages of Anaerobic Digestion (www.biostarsystems.com/whitepaper/BioStar\_Whitepaper\_093009\_.pdf)

1. In the Hydrolysis stage, complex organic molecules are broken down into simple sugars, amino acids and fatty acids with the addition of hydroxyl groups.
2. In the Acidification stage, acidogenic bacteria break the Hydrolysis stage products into simpler molecules and volatile fatty acids (VFAs). CO2 is produced, as well as NH3 and H2S. All of these are further digested by acetogens, to produce CO2, H2 and acetic acid.
3. Finally in the Methagenesis stage, biogas is produced by methanogens, leaving the digestate for further treatment.

The biogas produced can be separated into CH4 and CO2, which can be used as fuel and as a reactant in the Sabatier process respectively. The digestate has to be filtered and treated with chemicals in order to obtain potable water.

*Equipment*

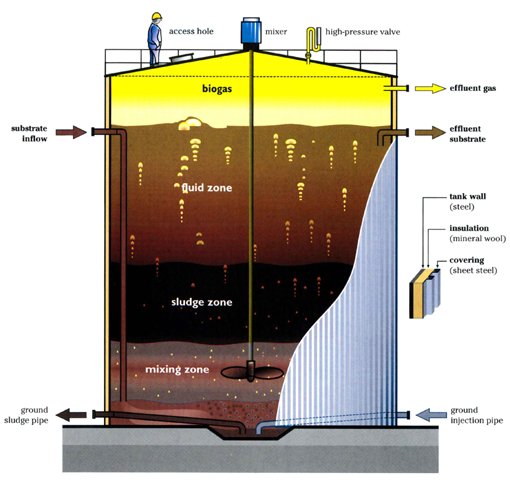


Figure 2: Basic Equipment Used (<http://www.daviddarling.info/encyclopedia/A/AE_anaerobic_digestion.html> (Haase))

The equipment used will be very similar to that seen in Figure 2. The stream to be treated enters the digester (airtight tank) which is well insulated. The tank is stirred by agitators to ensure thorough mixing, and also heated to either 30-35oC (mesophilic-explained below) or 50-55oC (thermophilic). The tank can be opened easily, allowing the removal/replacement/repair of individual agitators with no significant downtime. Agitators last 8-10 years, the tank roof lasts 10-20 years.

*Process Requirements*

To begin with the temperature of the digester has to be carefully monitored. *Mesophilic* operation results in a longer residence time (15-30 days), the need for a larger tank, but it is more reliable and easier to manage. *Thermophilic* operation takes 12-14 days, produces more gas (and hence less water), removes more pathogens, requires more monitoring and is more energy intensive.

As well as temperature, the pH of the digester has to be controlled. For optimum production pH 6-7 is preferred but the pH can extend to 5.5-8.5. Outwith this range the bacteria will be killed.

The solid content of the stream entering the digester is also important. If the solid content is high, additional pre-treatment (grinding for example) will be needed. A low solid content is preferred.

The carbon to nitrogen ratio in the tank is to be monitored also. A high C:N results in lower production, while a low C:N causes NH3 accumulation and a rise in pH…toxic conditions. An optimum ratio lies between 20 and 30.

The process is suitable for streams with COD content up to 50 000 mg/L and it is the preferred method when COD > 2000 mg/L.

*Production*

Figures are scarce for small scale AD plants and non-existent when considering the total amount of water that can be obtained. Simply put, this process is more suited for energy recycle than water production.   
  
*Advantages, Disadvantages and Conclusion*

* Low maintenance and repair
* Reasonable lifespan
* Multiple products that can be used for CHP, fertilizer, drinking water
* At most basic level (level needed for Mars), only 30mins/day monitoring
* Relies on bacteria to function
* **Not designed for water production**
* Delicate process with strict requirements for operation that must be met.
* Water produced is not useable until further treated
* More suited to large-scale use

Giving that the process is designed with biogas in mind rather than water production, and the reliance on keeping bacteria alive, this process is deemed to be non-feasible for use on Mars.

# Fermentation (Dark + Photo Fermentation)

*Process Description*

Dark fermentation involves the usage of facultative anaerobes or obligate anaerobes in order to convert waste streams into hydrogen and carbon dioxide. However, dark fermentation does not allow complete oxidation and hence some of the waste is formed into organic acids. As it is thermodynamically unfavourable to complete the oxidation in the dark fermentation stage, the dark fermentation can be combined with photo fermentation in order to process the organic acids further. Photo fermentation exposes the organic acids to photosynthetic bacteria (algae can be used) and a light source. This results in the organic acids being converted into hydrogen and carbon dioxide.  
  
For now, only dark fermentation will be examined. If the technique is deemed to be suitable, an investigation into photo fermentation will be performed. However, it is noted that photo fermentation requires further development for it to be of practical use.

Dark fermentation is the description used when the only carbon and metabolic energy source involved in the fermentation process is organic compounds. Theoretically, the maximum number of moles of hydrogen that it is possible to obtain is 4 moles per mole of glucose. This is found when acetate is the end fermentation product.

In practice, this is not achieved because of the formation of the organic acids. Hence, photo fermentation would be used to get as close to 4 mol H2/mol glucose as possible.

Like anaerobic digestion, the fermentation process does not directly produce water. The process itself would be more suited as a pre feed into the Sabatier reaction.

*Equipment*

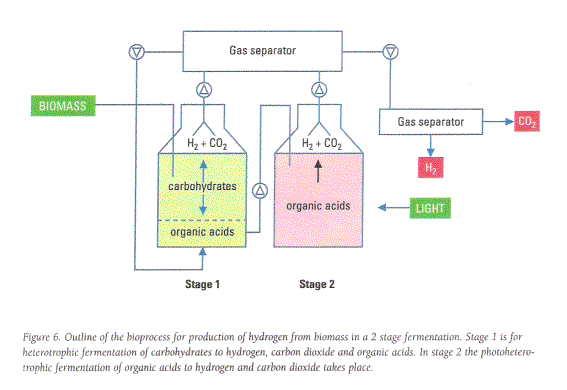
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Figure 3: Outline of the Fermentation Technique (http://www.microbes.jp/suiso/h2kiji/hb007.htm#51)

The main process outline can be seen in Figure 3. The waste streams are fed into a bioreactor that is operated under anaerobic conditions and contains facultative/obligate anaerobes. The organic acid that is produced is run off into another bioreactor, which contains photosynthetic bacteria/algae and is subjected to a light source. The gases created from these two bioreactors are passed through a gas/liquid separation stage, from which the liquid is recycled and the gas heads to another separation stage in order to split the hydrogen from the carbon dioxide. The hydrogen can then be further processed to produce water. As it is not currently widely used, equipment specifications exist only on a laboratory scale at this current moment in time.

*Process Requirements*

The process of dark fermentation is even more stringent than that of anaerobic digestion. The processes shares similar temperature, pH and C:N ratio restrictions. There is a slight difference in the values for each of these conditions, as dark fermentation is conducted at 35-55oC, an optimal pH of around 5.0-5.5 and a C:N ratio of 40-47. Dark fermentation also has to consider hydraulic retention time (HRT), the partial pressures of H2 and CO2 and the concentration of organic acid produced.

HRTs are used in CSTRs in order to wash out slow growing methanogens. This controls the dilution rate in the dark fermentation bioreactor. A HRT of around 3 days is ideal for this process. The dilution rate must not be allowed to get too high as it results in bad hydrolysis of the organic acids.

The partial pressure of H2 relates to the concentration of H2 in the liquid phase. The higher the concentration of H2, the lower the synthesis of H2 will be. This is because the metabolic pathways shift to the production of more produced substrates. The partial pressure has to be watched closely. For this system it will be around or slightly higher than 50kPa.

The partial pressure of CO­2 relates to the concentration of CO2 in the liquid phase. A higher concentration of CO2 in the liquid phase favours the production of fumarate or succinate, leading to a reduction in hydrogen production.

Finally, if the concentration of the organic acid is too high, there is a possibility of inhibition of hydrogen production. Again, this has to be closely monitored.

*Production*

Dark fermentation is seen as a major prospect for hydrogen production. However, it is currently at a laboratory scale and vitally, is not designed for the production of water.

*Advantages, Disadvantages and Conclusion*

* Dark fermentation process suited to Mars conditions
* Very simplistic design
* High conversion if dark/photo fermentation combination is used
* **Doesn’t directly produce water**
* Reliance on bacteria
* Very strict operating conditions
* Only currently used on an experimental level

As with anaerobic digestion, it is recommended that dark fermentation is not considered due to its products requiring further treatment to produce water, its reliance on bacteria and its lack of full scale testing.